CHAPTER 9

Air Quality

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❄ CRITICAL FINDINGS

Sierra-wide Status In northern Sierra Nevada airsheds, and in most remote areas during the winter, air quality is some of the cleanest in the nation and even in the world. Southern airsheds on the west side are heavily impacted during spring, summer, and fall by ozone and small particles derived from Central Valley sources and have some of the poorest air quality in the nation.

Ozone Damage Extensive ozone damage occurs to sensitive tree species at low and middle elevations on the southwest and central-western slopes.

Ozone Standards The federal ozone standards for human health may be inadequate to protect biota from air-pollution damage.

Smoke Smoke from managed fires on the average contributes only modest amounts of small particles to human lungs compared with other Sierran sources; winter smoke from woodstoves creates much more severe local air-quality problems.

Visibility Visibility is severely degraded for much of the western slope of the Sierra Nevada each spring, summer, and fall by fine-particle sulfates, nitrates, and smoke transported from the Central Valley.

Dust Dust storms over the alkali and dry lakes of the eastern Sierra (Mono Lake and Owens [dry] Lake) create severe episodic health hazards to humans and presumably to plants and animals as well, when transported into the White and Inyo Mountains and the Sierra Nevada.

ASSESSMENT

Air quality in the Sierra Nevada is highly variable in quality—excellent much of the time and in many places, seriously degraded at other times and places. Many early writers extolled the quality of the air, and in the early twentieth century the Sierra Nevada was even the site of sanatoriums. Yet the Sierra Nevada was typically quite smoky in the summers as many small fires burned for months until the rains extinguished them each fall. There are two distinct aspects of air-quality issues in the Sierra. The first relates to state and federal ambient air quality standards (ozone, particulate mass, visibility reduction), which are periodically violated in the Sierra Nevada. The second relates to air-quality impacts not subject to ambient-air standards (acid deposition, transport of air toxics, eutrophication of Lake Tahoe), which have a more ecological than human health focus.

At present, the most important deleterious impacts are closely tied to the efficient wind transport of air pollutants from the Central Valley of California into the western slopes of the Sierra Nevada up to elevations of 6,000 feet or more. This transport is strong in summer, weak or absent in winter, severe in the southern reaches, and more modest north of Sacramento, where mountain slopes are more gentle. Of these pollutants, ozone has the best documented and most important effects, especially in its connection to serious injury to Jeffrey and ponderosa pines. Fine-particulate sulfates, nitrates, and smoke are also transported by the same winds, especially between April and October, and sharply reduce visibility. Other components of valley air, including nitrates, pesticides, and herbicides, are also efficiently transported into the mountains and deposited on vegetation and in watersheds, often with poorly understood but potentially significant effects. For example, the suggestion that valley air-quality changes may be a factor in the precipitous decline of some amphibians since the late 1960s needs further investigation.

Degradation of air quality is one of the difficult questions raised by proposals for increased use of prescribed fire both to control high levels of forest fuels and to restore the functional role of fire. There is good documentation on degradation of air quality in massive uncontrolled fires. There is much less data on the effect of prescribed fires on a rangewide basis, and smoke from such events is difficult to detect in the detailed fine particulate mass records since 1988. Most information comes from local measurements taken at such fires and the visual effect of smoke. While quantities of smoke from prescribed fires are usually much smaller than from wildfires, they can, under exceptionally unfavorable conditions, also approximate wildfire levels. However, only very rarely does either type of smoke exceed the federal 24-hour fine-particulate mass standard.

High-elevation towns of modest population can still generate very high levels of fine particles in winter smoke, with levels higher than are typically seen even in the largest urban areas of California. Rather surprisingly, there is a rough equality between the mass of fine particles seen in winter urbanized areas and that seen near downwind of massive forest fires. Both of these can greatly exceed state and even federal 24-hour particulate mass (PM-10) standards. Lake Tahoe has sharply reduced water clarity and increased algae, some of which is tied to local and/or transported atmospheric air pollutants such as nitrates. Other typically urban air pollutants, such as carbon monoxide, have been high enough to warrant creation of special air standards to protect human respiration at these high-altitude sites.

The rapid desiccation of eastern Sierra Nevada lakes, Mono and Owens Lakes, has resulted in dust storms that in most years generate the highest 24-hour fine-dust levels in the United States. Much of this dust is transported into the Sierra Nevada and the White and Inyo Mountains, the latter being the home of the ancient bristlecone pines.

On the other hand, acid rain and snow are not as much a problem as in the eastern United States. No permanently acidified lakes or streams occur in the Sierra Nevada, although pulses of acidity can occur during spring snowmelt and during occasional summer thunderstorms in southern California deserts. In the winter, over much of the nonurbanized Sierra Nevada, levels of some human-origin pollutants such as sulfates are extremely low, mimicking even those of the high-altitude world baseline station on Mauna Loa in Hawaii.

In this section, we will examine a few of the most important topics concerning air quality in the Sierra Nevada, especially those aspects that may be improved or degraded by future human decisions.

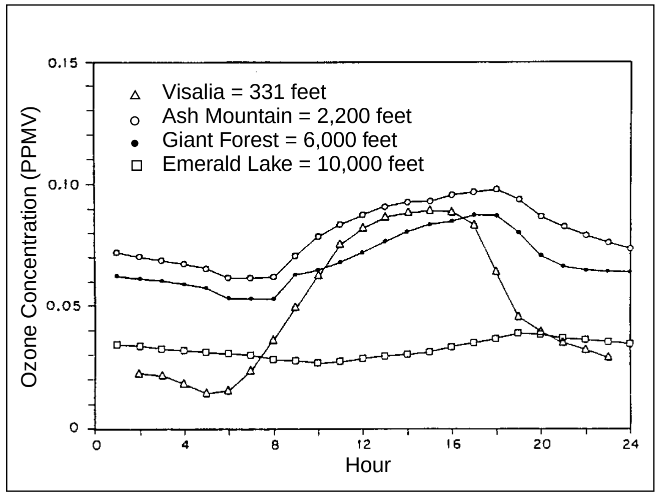


FIGURE 9.1

Daily ozone concentrations in parts per million in volume units (PPMV) at four different elevations in the southern Sierra. (From volume II, chapter 48.)

Ozone Injury to the Forests

Summer ozone is transported very efficiently from the valley floor into the Sierra Nevada by the remarkably strong and stable terrain winds that move strongly upslope each day and weakly downslope each night. The resultant daytime ozone levels between 2,000 and 6,000 feet are essentially as severe as those on the valley floor. At night, while valley ozone levels rapidly decrease, ozone levels in the mountains stay high, with unknown impact in the morning when the stomata of plants open at first light. Figure 9.1 shows the relationship of elevation and summer ozone influence at sites in and near Sequoia National Park. The peak ozone level at Visalia, on the valley floor, is essentially the same as that at Ash Mountain (2,200 feet) or Giant Forest (6,000 feet). Only when elevation approaches 10,000 feet at Emerald Lake does the valley ozone influence seriously decrease.

These ozone levels lead then to ozone exposure, which is the product of the ozone concentration times the number of hours each concentration occurs. New relationships have been derived for this study that give precise damage measurements to forest trees, especially the economically important Jeffrey pine and also ponderosa pine. The trend of injury, calculated as the ozone injury index, decreases from south to north. Also shown is a measure of exposure, using 0.09 ppm as a cutoff. Exposure above this threshold, which also happens to be the California hourly standard (the federal standard is 0.12 ppm), matches very well with observed damage. Peak ozone hourly concentration does not match the damage indices nearly as well.

Poor Visibility

Visibility depends upon the concentration of fine particles, in fact the same particles that can penetrate deep into the lungs. Thus, to a good approximation, how far you can see is a measure of what gets into your lungs. When measured at high altitudes in the national and state parks, the fine particles are very low in winter and high in summer. Levels are almost always higher at Sequoia National Park than Yosemite National Park or D. L. Bliss State Park at Lake Tahoe. Measurements at Lassen Volcanic National Park are about the same as those at Bliss State Park.

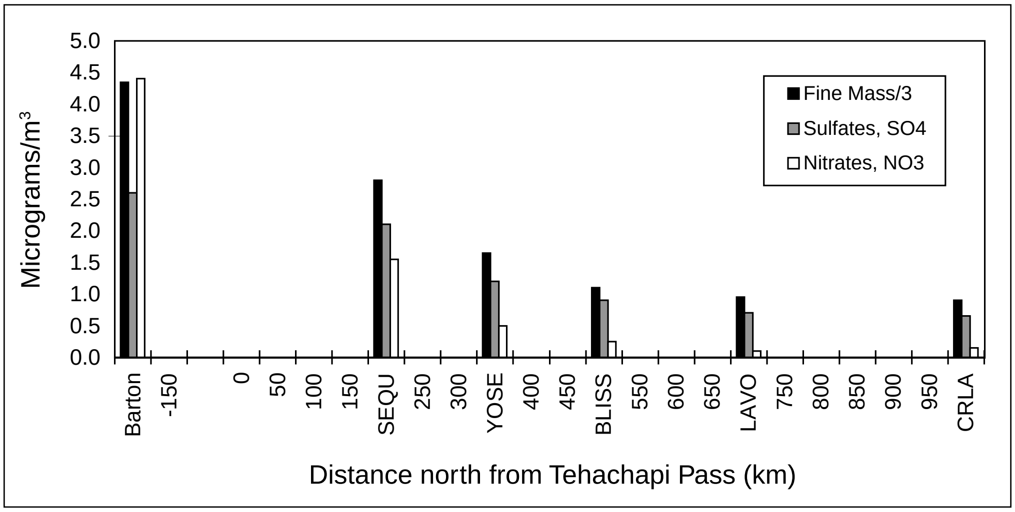
Particles may be either primary, such as dust, pollen, and smoke, or secondary, such as sulfates and nitrates. As with ozone, emissions of precursor sulfur and nitrogen gases that lead to the secondary particles largely originate from human activities that release sulfur dioxide (largely from Bay Area and southern San Joaquin sources) and nitrogen dioxide (mobile and stationary sources). Particle concentration of sulfates and nitrates roughly reflect the same north to south increase seen for ozone exposure. Figure 9.2 shows the annual concentrations of fine mass, sulfates, and nitrates for park and wilderness area sites. Smoke, an important component of fine-particle pollution in the summer, has a significant origin in biomass burning in the valley, including wheat and barley stubble, levee maintenance, and so on, but not including rice straw, which is burned later in the year.

Deposition of fine particles, especially sulfates and nitrates, on vegetation, soils, and bodies of water has unknown but potentially significant effects. The introduction of nitrates and sulfates into the Sierra Nevada hydrological cycle leads to the possibility of permanent or ephemeral acidification of lakes and streams, exacerbated by the generally low buffering capacity of high Sierra granite watersheds.

Although these same fine particles contribute to wet deposition in winter, levels of sulfates and nitrates are lower than in summer, especially north of Yosemite National Park. Again, the influence of upwind sites can be traced directly into the

FIGURE 9.2

Concentrations of fine aerosols, including fine mass, sulfates, and nitrates, along a south-to-north gradient (San Bernardino National Forest to Crater Lake National Park, Oregon) for 1992–93. Fine mass values are divided by 3 to fit on the graph. (From volume II, chapter 48.)



mountains. Sulfate and nitrate concentrations in snow have only a modest (about 50%) increase in concentration as one goes from north to south in the range.

Health and Ecological Effects of Urban Winter Smoke

Mountain valleys easily form atmospheric inversions, which are especially strong in winter. These trap local pollutants close to the ground, leading to extreme levels of fine particulate mass. Some of this mass may, however, be water trapped in smoke by wood combustion, so that the health effect of these winter episodes may not be commensurate with the apparent mass loading. Still, because the loading is so extreme, efforts to reduce fine particulate mass are well taken.

To put this problem into perspective, figure 9.3 shows typical winter smoke at Truckee, an area that forms a strong winter inversion, compared with the worst day of the catastrophic Cleveland wildfire of 1992. The levels are essentially identical. However, the Truckee pollution extended only a very short distance from the town center in winter, since it is very local, while the concentrations in the Cleveland fire extended over perhaps a few hundred square miles. On the other hand, the winter smoke levels occur on a good fraction of all winter nights, while the Cleveland fire was an infrequent event that lasted only three days.

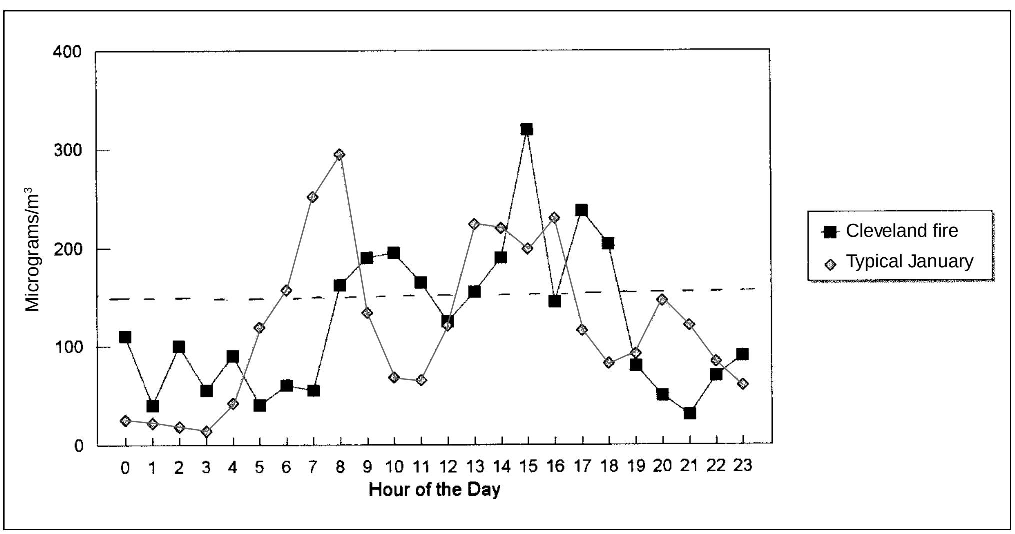
Smoke from Wildfire and Prescribed Fires

The increased fuel loading in the Sierra Nevada consequent to the suppression of burning in the twentieth century will almost certainly result in greater smoke concentrations in the future. The only questions appear to revolve around the nature of the fires, wild or prescribed, and the times and places under which they occur.

Prescribed fires may be human-initiated controlled burns

FIGURE 9.3

Comparison of large particulate matter (PM-10) levels at Truckee, California, for the peak day of the Cleveland wildfire, 9/30/92, and a typical winter day, 1/6/92. (From volume II, chapter 48.)



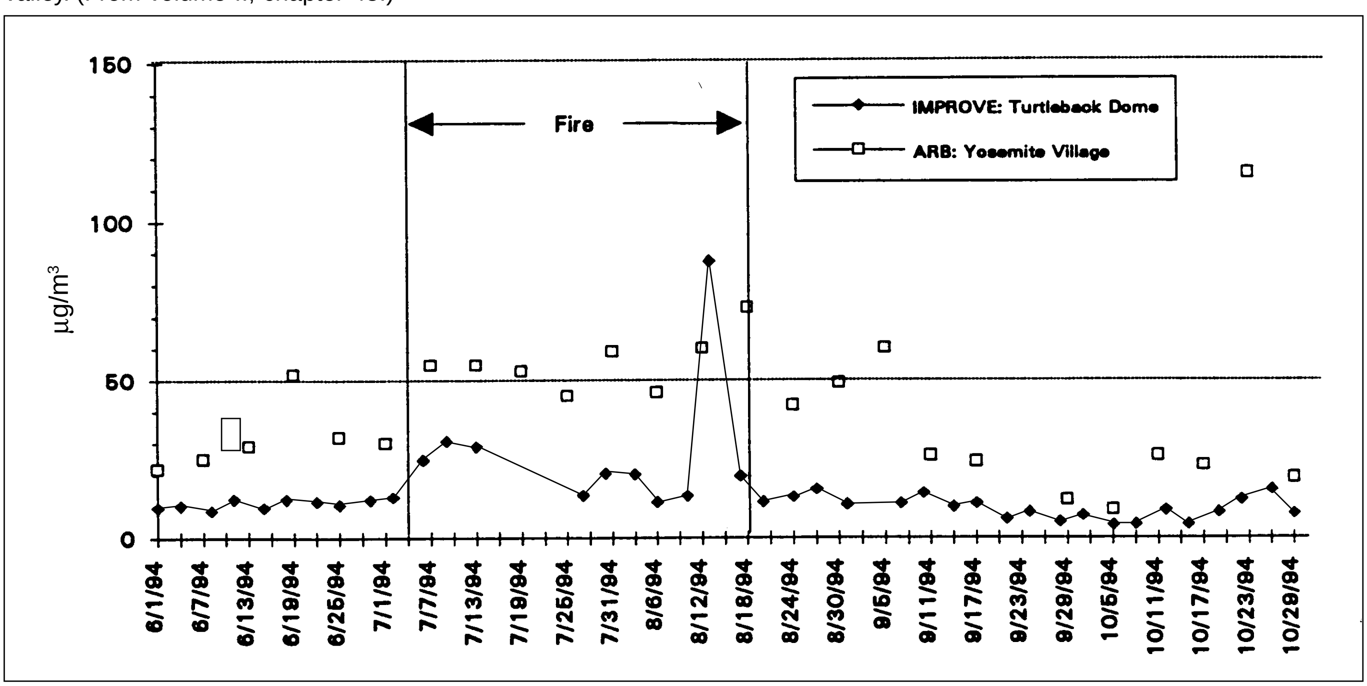
Visibility at Yosemite National Park. Several days each winter and spring are as good as or better than the left photo, but several days each summer are as bad as or worse than the right photo. Park air quality is the result of local smoke and nitrates, sulphates, and smoke transported from the Central Valley. (Photos courtesy of the National Park Service Air Quality Division.)

or lightning-started fires allowed to burn under certain conditions (prescribed natural fires). Air sampling sites in the Sierra Nevada have been able to detect such smoke on only a couple of occasions; though often very visible, smoke is generally only a minor contribution to fine particle mass loading. For example, a prescribed natural fire burned for a month near the Turtleback Dome air sampling site in Yosemite National Park. Mass concentrations for this event are shown in figure 9.4 along with the particle mass measurements due mostly to campfires on the floor of Yosemite Valley. The prescribed natural fire generally resulted in an average of about 10 micrograms per cubic meter of mass, and only one measurement (85 $\mu g/m^3$) exceeded the state standard (50 $\mu g/m^3$).

An important contrast can now be seen between fine particles generated by wildfires and those from prescribed fires. As much or more acreage was burned per day in the Cleveland wildfire (7,000 acres per day) as is generally burned each year in prescribed fires in a typical national forest. The gen-

FIGURE 9.4

Concentrations of large particulate matter (PM-10) in Yosemite Village, Yosemite National Park, June through November 1994, as measured by the California Air Resources Board, and data from the IMPROVE sampler at Turtleback Dome high above the valley. (From volume II, chapter 48.)



eral lack of obvious fine-particulate-mass impact from prescibed natural fire is due to the care taken in selecting favorable meteorology, burning conditions, and so on. Federal and state health standards for fine particulate mass would probably not be violated were the rate of prescribed fire accelerated by as much as a factor of five. There are, however, examples of prescibed fires that have failed to comply with air-quality standards because they did not pay close enough attention to meteorological factors or to the importance of dispersing burns in both time and space. One example involves prescribed fires near Sequoia National Park that burned on into an exceptionally dry fall (1995) as smoke dispersion became poorer. The effect was high smoke levels in downslope communities that roughly equaled the urban smoke present in high-altitude towns in winter.

Another point worthy of mention is the size of smoke particles. Whereas uncontrolled wildfires generate a considerable component of coarse mass, residential woodstoves and other slowly burning fires generate mostly fine particles. The U.S. Environmental Protection Agency is at this moment considering moving from a relatively coarse particle PM-10 standard (particles below 10 micrometers diameter, either 24-hour or annual concentration), to a finer particle standard (probably particles below 2.5 micrometers, annual average) more closely tied to health effects studies. While the finer particle standard will heavily impact smoke, an annual average standard would allow for a few days of higher concentrations if at other times the average concentration was low. This is the case at most Sierra Nevada sites, at least outside of cities.

In summary, one of the more unexpected results of the study was an approximate equality between maximum 24-hour PM-10 concentration in smoke from very different sources. All were above 100 $\mu g/m^3$, occasionally even exceeding the federal standard of 150 $\mu g/m^3$:

- The Cleveland wildfire west of Lake Tahoe, September 1992, burning at the rate of 7,000 acres per day, in hot, dry conditions, with good ventilation, towering smoke clouds covering hundreds of square miles, and burning for about three days.
- The fires near Sequoia National Park, fall 1995, started as prescribed fires, burning at a rate of about 300 acres per day, in dry, stable fall conditions with decreased ventilation, a low-elevation smoke cloud covering tens of square miles, with a duration of about thirty days.
- The typical winter smoke in towns like Truckee, largely from, at most, a few thousand domestic wood fires, in a strong winter inversion with poor ventilation, generating a shallow layer of smoke trapped in a valley that, for Truckee, probably did not cover even a few square miles.

The latter conditions are common for about one-third to one-half of all winter days in towns from Quincy to Mammoth Lakes.

This study and others also supported a relationship between smoke mass and visibility showing that at the federal standard one can see about two miles and at the state standard about six miles. The visibility problems of smoke can be major even at smoke levels that do not reach health-based standards on particulate mass.

The Degradation of Lake Tahoe

The Lake Tahoe air basin, especially the built-up areas at the south and north ends of the lake, experience seriously degraded air quality each winter. In addition to health and visibility effects, the ecological effect of air pollution on Lake Tahoe appears significant. Figure 9.5 shows transport of materials into the Lake Tahoe Basin as a function of time of year. The site at D. L. Bliss State Park, near Emerald Bay on the west shore, in effect, samples air equivalent to that in the Desolation Wilderness Area and the associated transports from upwind sources. The difference between the Bliss data and the South Lake Tahoe data thus represents the local contribution to fine particles. For sulfates, local sources are minor at all times. For other pollutants, such as organic matter and nitrates, there are massive winter enhancements at South Lake Tahoe, at which time transport from upwind sources is sharply decreased because of the trapping of pollutants in the Central Valley.

The low concentration of transported nitrates, and their small particulate size, must be contrasted with the high levels of local nitrates from the highways that ring the lake. The coarser winter nitrate particles are more likely to settle into Lake Tahoe than the fine particles transported from the Central Valley each summer, but the latter extend across the entire area of the lake. Direct nitrate deposition measurements are difficult to do, and the issue is still controversial. Fine particles are thus triply important at Lake Tahoe as they affect visibility, degradation of the lake, and human health concerns.

The Future of Air Quality

Air quality in the Sierra Nevada is at a critical point, with moderate to severe degradation becoming all too often accepted as the status quo. Ozone is in a holding pattern despite massive efforts to control primary transportation sources. Clearly, the Central Valley is not like California's urban areas, where ozone is in decline; this fact increases concerns for future Sierra Nevada air quality as valley and foothill populations grow. Except at Lake Tahoe, little effort is being made to address reduced visibility, which, to the average visitor, is the most evident sign of degraded air quality. Yet most of the haze seen today comes from the Central Valley, a change from the past. Very little is known about the effects of other substances, including herbicides and pesticides, that may be transported into the Sierra Nevada from sources such as the Central Valley. We also now know that there is an air-quality

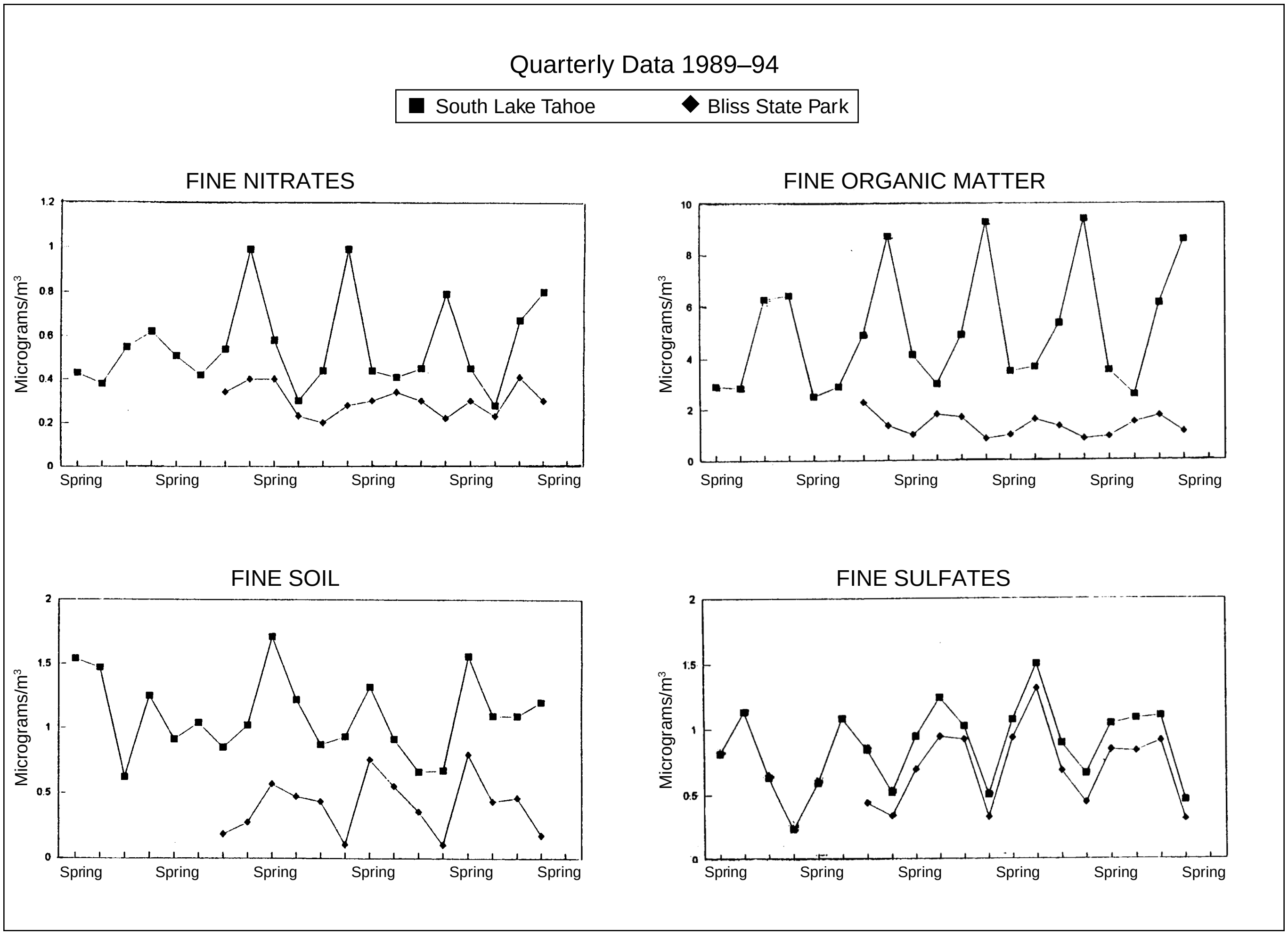


FIGURE 9.5

Concentrations of aerosols at two sites at Lake Tahoe (South Lake Tahoe and D. L. Bliss State Park) over the seasons, 1989–94. (From volume II, chapter 48.)

component, local and transported, in the decline in the clarity of Lake Tahoe's waters. The future will almost certainly bring more forest smoke, from either wildfires or prescribed burns, in response to the fuel buildup of the past ninety years.

There are areas within the Sierra Nevada for which air quality is improving. It was no accident that areas that were in rapid and demonstrable decline, first Lake Tahoe and then Mono Lake, also engendered the most effective scientific, legal, political, and regulatory responses. The dust problems at Mono Lake will soon decline as the lake's water level rises in response to recent legal and regulatory actions. Now urbanized enclaves in the mountains (Lake Tahoe, Mammoth Lakes) are also showing some progress, partly through improvement in vehicles, partly through controls on woodstoves and other sources.

Finally, there are factors of potential importance to air quality that are still quite uncertain; many of these are tied to changes in the global climate. Scientists are confident that there has been a 25% increase in carbon dioxide and a doubling of methane in the past century, and an order of magnitude increase in chlorofluorocarbons in the past twenty years. Also, an overall small temperature rise and a small (less than 3%) increase in ultraviolet radiation are becoming apparent and may have influences yet to be determined. Less certain are predictions of increased climatic variability, an increase in summer rain, decrease in summer snow, and more frequent El Niño events, which can generate either drought or intense rainfall at different phases of the cycle. Model predictions for these and other potential air-quality influences are uncertain.

AN AIR-QUALITY STRATEGY

Goals

Three primary goals for an air-quality strategy for the Sierra Nevada are:

1. Reduce ozone levels and associated impacts.
2. Reduce fine-particle pollution and associated impacts.
3. Minimize smoke levels while maximizing the beneficial use of fire.

Possible Solutions

Ozone

Through rigid enforcement of the current California state standard of 0.09 ppm ozone, peak hourly rate, only modest damage would be expected for plant species known to be sensitive. Note that acceptance of the federal standard of 0.12 ppm, peak hourly rate, would not result in elimination of vegetation damage. New technology has been adopted and allows for identification of “grossly emitting” vehicles as they drive along the highway; removing these vehicles from service provides an effective means of significantly reducing emissions. In addition, reformulated gasolines now coming into use further reduce emissions of ozone precursors.

The dramatic decline of peak ozone concentrations that have been seen in recent years in areas like Los Angeles with high vehicular densities are not being seen in the Central Valley. Thus, it has become evident that confounding valley sources must exist. Most likely is the intense biological activity associated with agriculture and its accompanying emissions of hydrocarbon and ozone precursor gases. Also, regulatory controls have to date been somewhat less stringent in the Central Valley than in Los Angeles. The federal and particularly the state air-quality agencies are beginning to pursue ozone control measures associated with these apparent sources.

Fine-Particle Pollution

The Clean Air Act of 1977, extended by the amendments of 1990, mandates the mitigation of human sources of fine-particle pollution insofar as they degrade visibility in Class I areas such as Yosemite National Park. This can be accomplished by enforced limitations of upwind emissions of sulfur in the Bay Area and San Joaquin Valley, especially the oil refineries and chemical plants near the Carquinez Strait; continued efforts to control oxides of nitrogens, and tighter controls on or elimination of all agricultural burning during summer months. These measures would result in sharply improved visibility and the accompanying reduction of fine-particle deposition.

Smoke

Increasing by a factor of five the annual acreage of Sierra Nevada forests burned by surface-burning controlled burns and prescribed natural fire would reduce overall pollution from smoke. Burning would be concentrated in spring (mid-April through mid-June) and fall (mid-September through mid-November) to avoid coinciding with peak summer levels of smoke originating in the Central Valley. The increase in local and subregional smoke associated with prescribed burns must be traded off against the large regional smoke plumes of the wildfires that can be expected without increased prescribed burning.

Smoke originating from residential areas within the Sierra Nevada can be reduced by burn and no-burn days, highly efficient woodstoves, and changes in fuel from local pine to dried fruitwoods. Even more beneficial is an increasing transition from woodstoves of all kinds to natural gas, when available.

Implications

Meeting the air-quality goals has three principal implications:

1. Evidence indicates that if peak hourly ozone values remain below 0.09 ppm, injury to Jeffrey pine, ponderosa pine, and other sensitive species would be decreased.
2. The economic values associated with tourism would be enhanced by higher scenic visibility. Deposition of potentially harmful pollutants on vegetation, soils, and hydrologic systems would be reduced.
3. Comparing data from the 1992 Cleveland fire in the Eldorado National Forest with calculations for optimizing a fivefold increase in the annual controlled burn acreages for this same forest, indications are that there would be drastically lower levels of regional particle loading achieved by the application of human prescribed fire. Levels would be even less than the average daily winter levels typical for the woodstove smoke component at mountain communities like Truckee.

Although the particulate pollution levels from this strategy meet state and federal standards and would not greatly increase particulate smoke in towns downwind, it is not true that there would be no impacts. Fires, besides being unsightly, can carry allergens to susceptible human populations, with accompanying short-term respiratory impacts. This effect limits the amount of material that can be burned at any one time and place and should caution application of prescribed fire that would overlap with winter smoke problems already typical of some urban areas.

The proposed new federal fine-particulate standard, conceived as an annual average based upon a 2.5 micrometer cut point (PM-2.5), would put additional pressures on mountain urban communities to control winter smoke levels. The standard would actually favor this strategy, because the additional smoke from prescribed fires would not be exacerbating already elevated urban levels.

Spatial trends for air-quality concerns have been noted from the northern to the southern end of the Sierra Nevada. Trends for west to east transport of Central Valley and Bay Area pollutants are also clearly mapped, with many sources displaying clear signatures to the sophisticated monitoring apparatus already in place. Continued and enhanced monitoring will provide ample opportunity for gauging and interpreting the success of reducing Bay Area sources of fine particles, valley sources of biomass burning and ozone generation, and smoke from prescribed fire versus wildfire in the Sierra Nevada itself. A reversal of current trends would be obvious.

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